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# Application of LANDSAT Imagery for Snow Mapping in Norway

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LANDSAT-2 Contract 29020  
Final Report  
Johnny E. Skorge

(E78-10041) APPLICATION OF LANDSAT IMAGERY  
FOR SNOW MAPPING IN NORWAY Final Report, 16  
May 1975 - 27 Aug. 1976 (Norwegian Water  
Resources and Electricity) 29 p  
HC A03/MF A01

N78-14458

Unclass

CSCL 08L G3/43 00041

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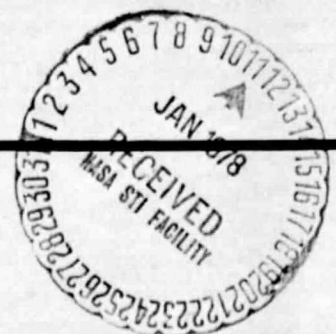
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Prepared for  
National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, Maryland 20771

A Separate Study under Project No. 29020  
"Hydrological Investigation in Norway"



1. Proj. No.: 29020	2. Type of Report: FINAL	3. Recipients' Catalog No.:
4. Title: APPLICATION OF LANDSAT IMAGERY FOR SNOW MAPPING IN NORWAY.		5. Report Date: May 25, 1977
		6. Period Covered: 16.5.1975 - 27.8.1976
7. Principal Investigator: Helge Ødegaard		8. No. of Pages: 26
9. Name and Address of Principal Investigator's Organization:  Norwegian Water Resources and Electricity Board, P.O.Box 5091, OSLO 3, Norway		10.
		11. GSFC Technical Monitor: Mr. F. Gordon
12. Sponsoring Agency Name and Address:  The Royal Norwegian Council for Scientific and Industrial Research (NTNF) Space Activity Division Wdm Thranesgt 98, OSLO 1, Norway		13. Key Words:  Snow mapping Snow line Equivalent snow line al- titude Cumulative runoff
14. Supplementary Notes:  This is a separate study by Johnny Skurve, Co-Investigator in: Hydrological Investi- gations in Norway. Address: Kirkeveien 127, OSLO 3, Norway		
15. Abstract:  The snow cover in four basins in southern Norway have been studied. By use of data from 1975 and 1976, it has been possible to observe nearly one complete melting season with the use of LANDSAT imagery. The observations cover the period from the middle of May 1975 to the end of August 1976.  The four basins represent different climatological conditions, and cumulative runoff information is compared with the rate of decrease in areal extent of the snow cover in each basin.  <div style="text-align: right;">Original photography may be purchased from: EROS Data Center  Sioux Falls, SD</div>		

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## SNOW MAPPING IN SOUTHERN NORWAY BY USE OF LANDSAT IMAGERY.

### THE BASINS

The areal extent of the four basins in the study area are:

OLDEN	222 km <sup>2</sup>
BREIM	636 km <sup>2</sup>
JOSTEDAL	834 km <sup>2</sup>
BOEVRA	895 km <sup>2</sup>

The Boevra and Olden valleys have rivers that run northward, while those of Jostedal and Breim are heading respectively in southern and western direction. Compare Figs. 2,3,4,5,6 and 7.

### GENERAL DESCRIPTION

Four drainage basins in mountainous Norway were selected for a study in snow mapping by use of LANDSAT imagery. The basins are distributed along an east-west line and they represent different climatological conditions. In the eastern parts of the area the precipitation is only 10-20 per cent of the amount in the westernmost parts. Not only does the climate differ from basin to basin, but also within each one of them, though the basins are rather small. This is due to the fact that within a relatively short distance, we find both Norway's wettest and driest parts. All four basins in the study area have glaciers (compare Fig. 7), which complicates the relation between runoff and snow-melt. The difference in climate within the area as a whole has consequences for the pattern of snowmelt.

LANDSAT imagery clearly shows an obvious difference between east and west. In mountain areas SE of the study area, great changes in snowcover took place in the course of 18 days in July 1975, while the snow distribution pattern in the western mountains was much more stable, with smaller changes in areal extent. This slower change in snow-melt pattern, makes the area less sensitive to the effect of LANDSAT's infrequent image coverage because of the 18 days' observation cycle. This is, however, compensated to some extent by the fact that in this high latitude (61-62°N) there is some 60% image overlap on two consecutive days.

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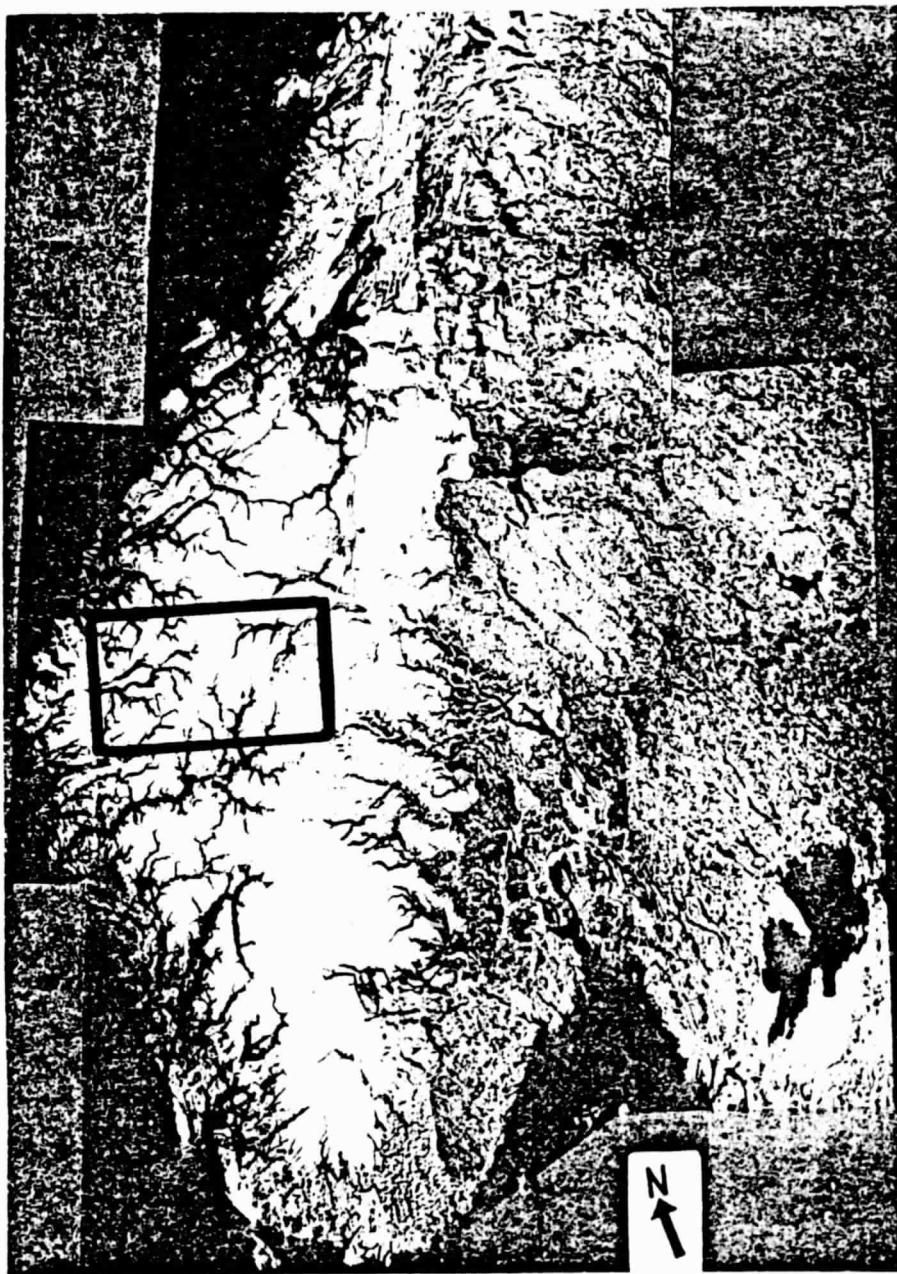


Fig. 1

The study area is situated within the rectangle drawn on this uncontrolled LANDSAT imagery mosaic of Norway south of the Arctic circle.

(Mosaic by Johnny Skorve.)

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Fig. 2

This LANDSAT MSS 5 image from May 18, 1973, shows the snow situation during spring in south-western Norway. The boundaries of the four basins studied, have been drawn. From left to right: Breim, Olden, Jostedal and Boevra.

Scale 1:1,5 mill. Image No.: 1299-10204

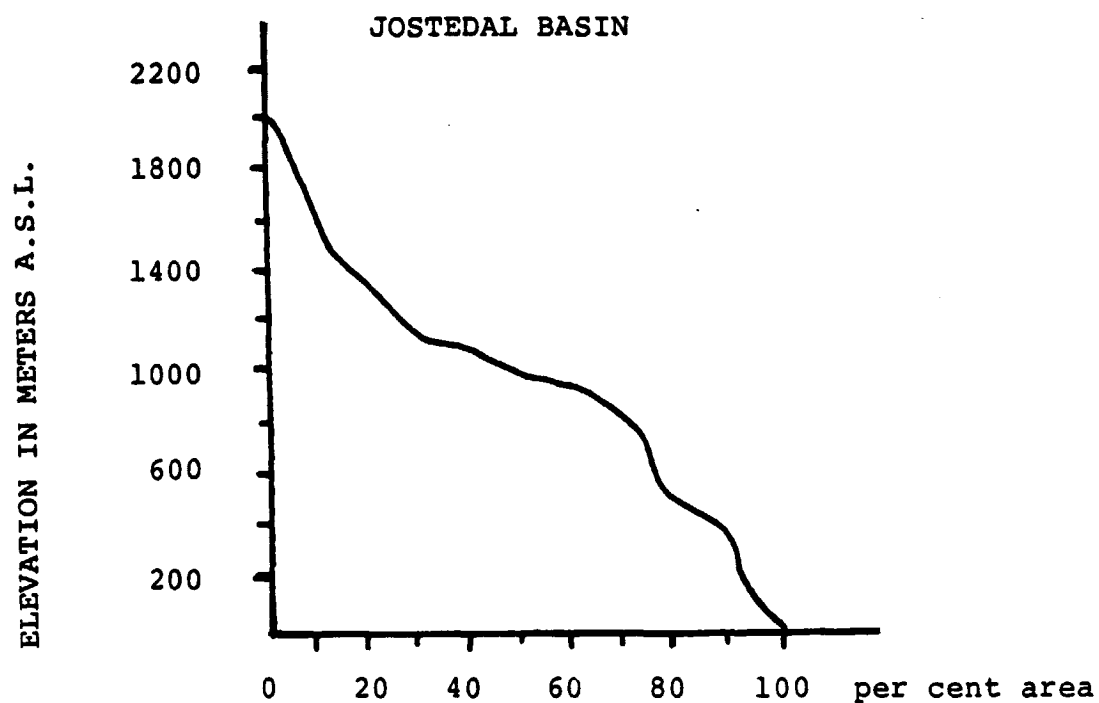


Fig. 3 Elevation distribution

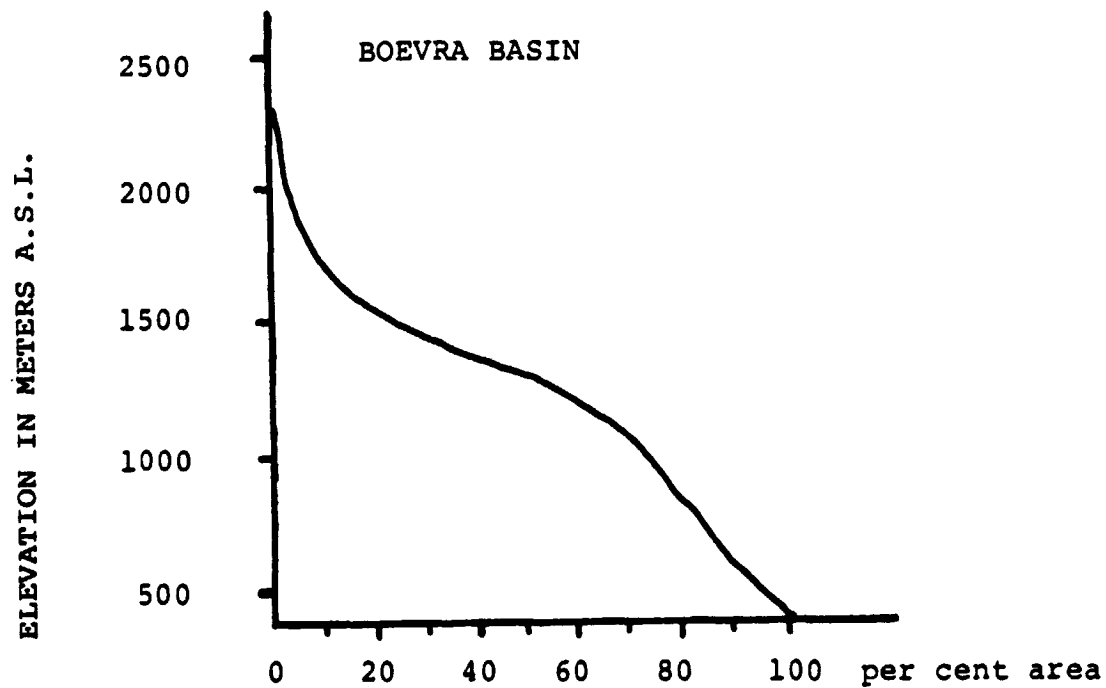


Fig. 4 Elevation distribution



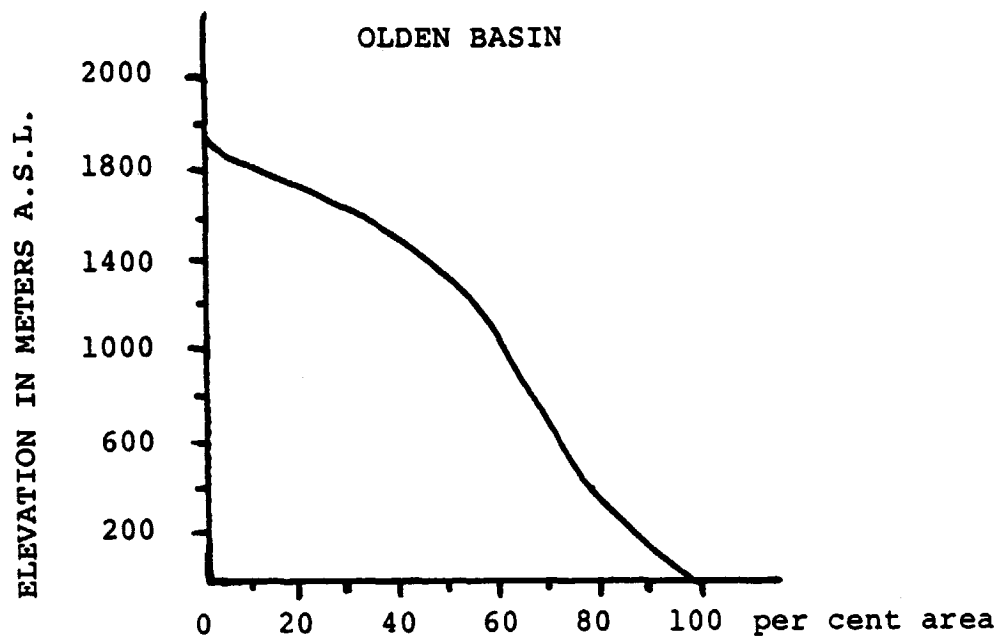


Fig. 5 Elevation distribution

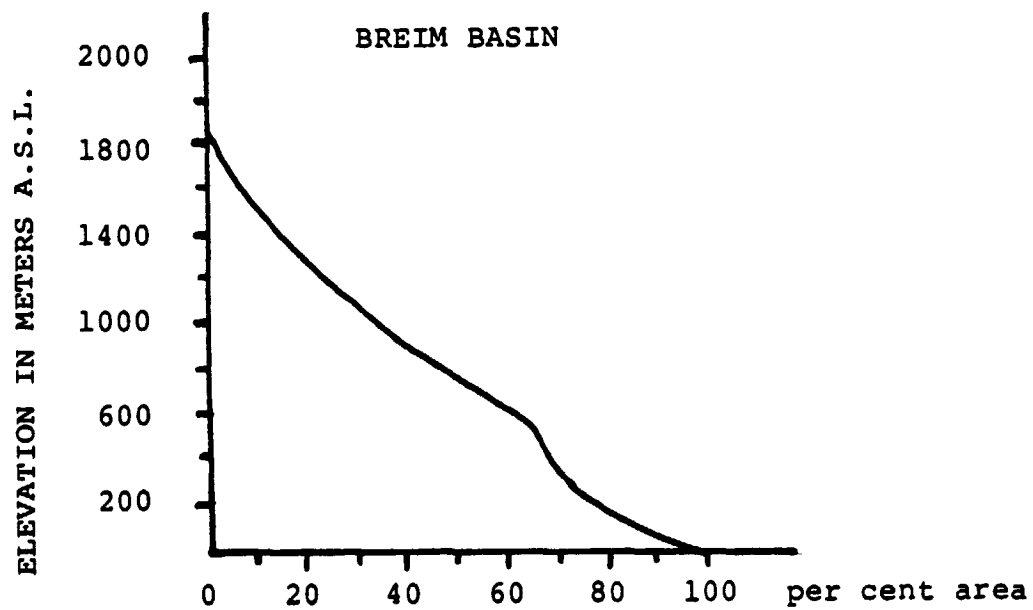


Fig. 6 Elevation distribution

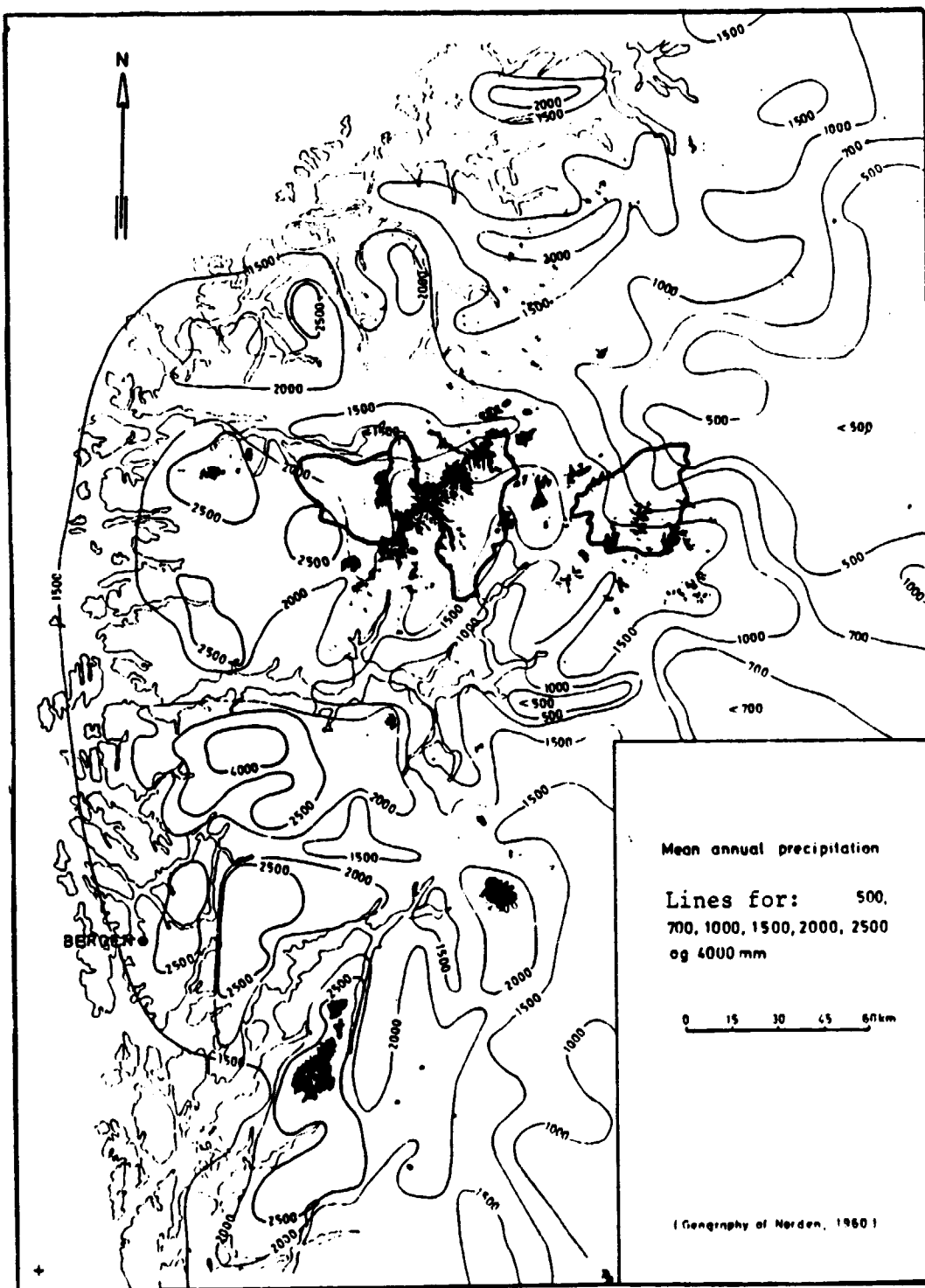


Fig. 7

The four basins in the study are drawn on this mean annual precipitation map of southwestern Norway. From left to right: Breim, Olden, Jostedal and Boevra.

A limited number of LANDSAT images were acquired in 1975 with no scenes later than July 28. This resulted in an incomplete picture of the snow-melt in the western mountain areas since appreciable amounts of snow was still present at the end of July. Fortunately, some LANDSAT images were also taken of the study area during the summer of 1976 with two cycles in August. Both the 1975 and the 1976 summers were sunny and warm and most of the LANDSAT scenes acquired during these periods were cloud-free or nearly cloud-free. Both preceeding winters produced considerably more than a normal snowpack.

#### THE GEOGRAPHICAL AND CLIMATOLOGICAL SETTING

The area studied is situated at about  $61,5^{\circ}\text{N}$  and between  $6$  and  $9^{\circ}\text{E}$ .

The Boevra basin includes the highest mountains in Norway with the Jotunheimen peaks close to 2500 m.a.s.l. (8100 feet). The three other basins are closer to the sea and all cover parts of Jostedalsbreen, the largest glacier in Norway. The highest parts here are just above 2000 m.a.s.l. (6500 feet). The whole area is dominated by westerly winds resulting in temperate winters and summers. Even during the coldest part of the winter, the average temperature along the outermost part of the coast is above freezing (at sea level). The precipitation is heavy, some places receive more than 4000 millimeter (160 inches) per year. The precipitation diminishes rapidly eastwards. 200 kilometer further east the climate is almost continental with only 300 millimeter (12 inches) of precipitation per year, compare Fig.7.

#### THE TIMBER LINE

In the east and central parts of southern Norway the climatic timber line altitude lies between 1000 and 1200 m.a.s.l. (3300-4000 feet), while it is as low as 400 m.a.s.l. (1300 feet) in the western coastal areas of southern Norway.

In connection with the use of LANDSAT-data for snow mapping, it is very important to recognize the importance of the timber line altitude in Norway. Nearly all of the important basins have most of their areas above the timber line. Therefore, snow in forest-covered areas is not a big problem for users of LANDSAT-data in Norway. This fact makes LANDSAT imagery more suitable for snow mapping in Norway than for countries at lower latitudes where the timber line is considerably higher than in Norway.

#### GROUND-BASED DATA ON SNOW-COVER

To get a better understanding of the snow situation, ground based information was used. Data of this type are available on a type of special "Snow accumulation maps" that are issued by the Norwegian Meteorological Institute on a regular basis each winter.

The relative snow accumulation is calculated for three levels; 400, 800 and 1200 m.a.s.l. (1300, 2600 and 4000 feet). The isolines on the maps show the percentage of normal snowpack in these altitudes. The last set of maps of a season show the situation at the end of April which is close to the date when the snow starts to melt (compare Figs. 8, 9, 10 and 11). Snow data from some weather stations have also been used. Both the winter seasons of 1975 and 1976 were characterized by heavy snow accumulation in the mountain areas in south-western Norway. In 1976, parts of the study area received more than 200 per cent of the normal snowpack.

#### RUNOFF DATA

The runoff data used in this study have been obtained from discharge stations near or at the base of the four basins. The Norwegian Water Resources and Electricity Board provided most of these data, the rest were made available by the Geographical Institute of the University of Oslo.

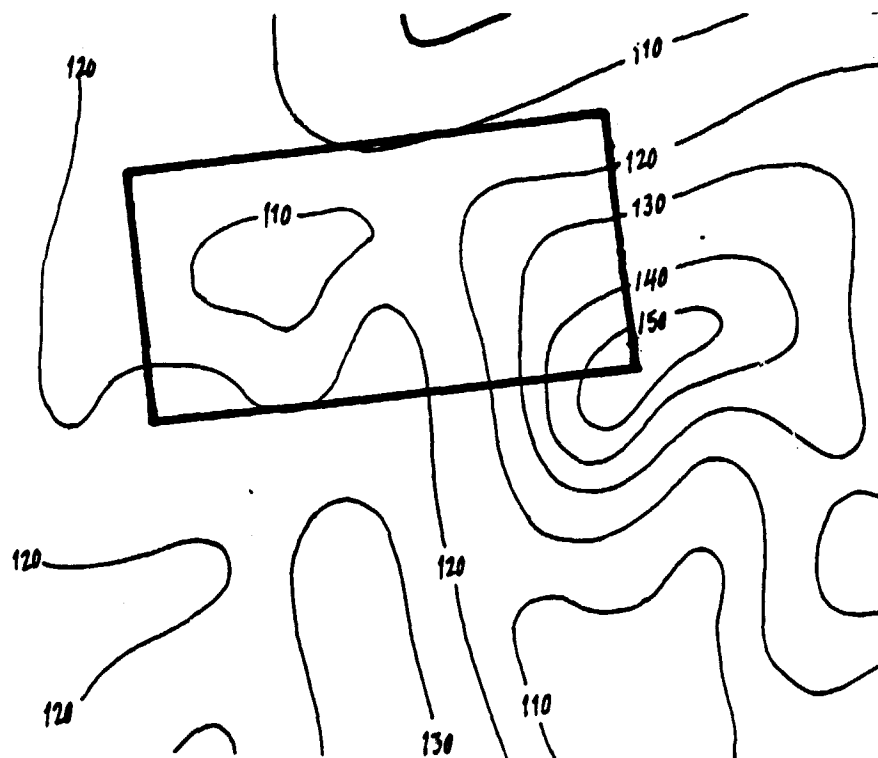


Fig. 8

The isoline map shows per cent of normal snowpack in the 1200 meter a.s.l. on April 30, 1975. The study area is situated within the rectangle.

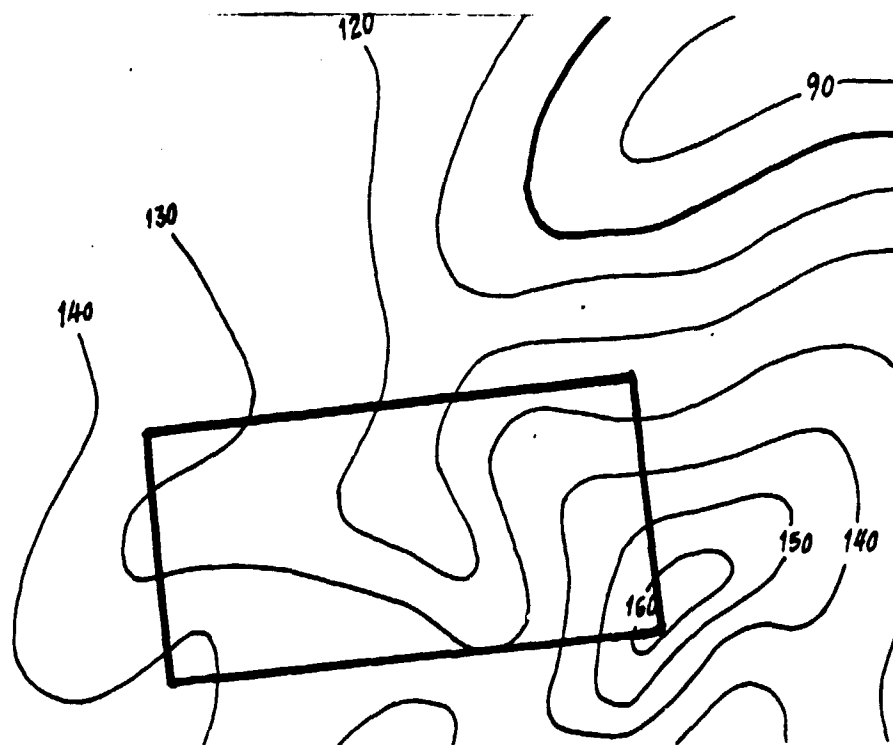


Fig. 9

The isoline map shows per cent of normal snowpack in the 800 meter a.s.l. on April 30, 1975. The study area is situated within the rectangle.

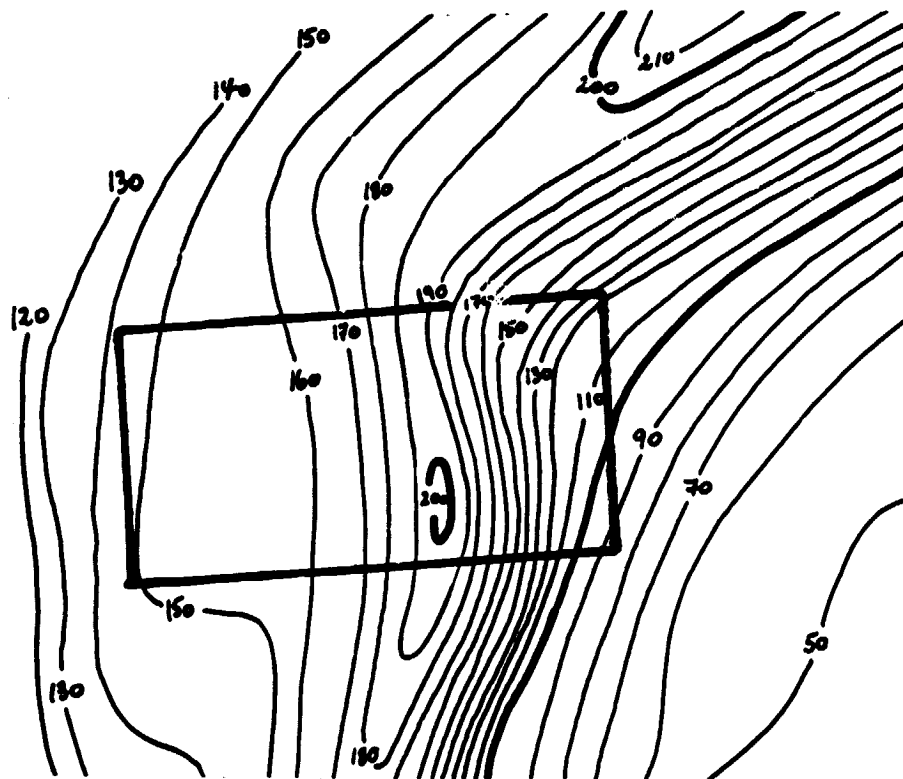


Fig. 10

The isoline map shows per cent of normal snowpack in the 1200 meter a.s.l. on April 30, 1976. The study area is situated within the rectangle.

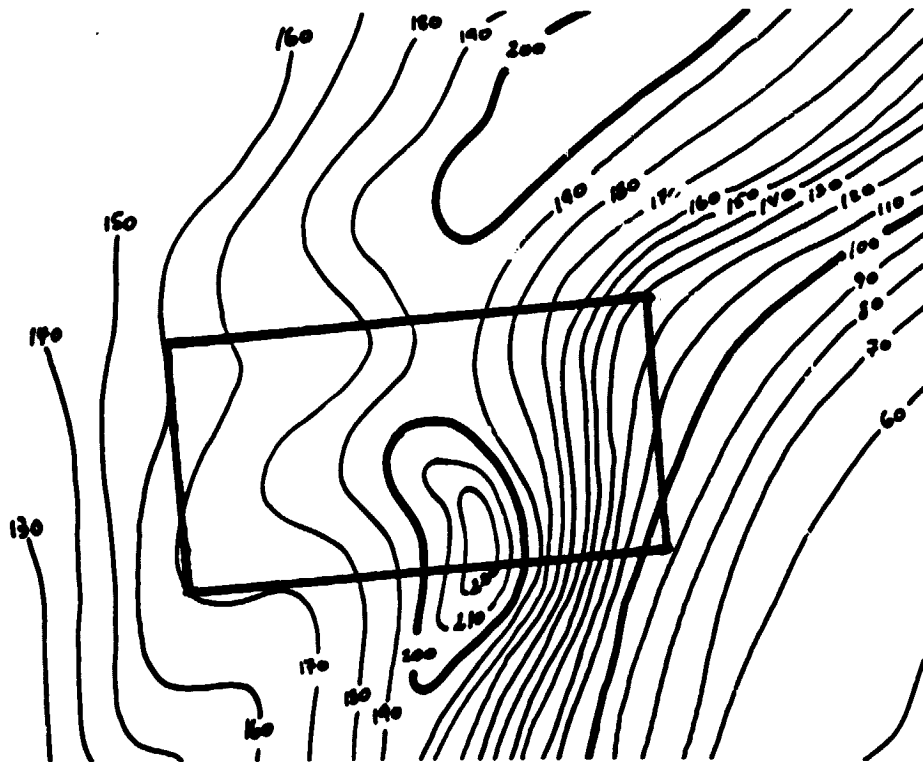


Fig. 11

The isoline map shows per cent of normal snowpack in the 1200 meter a.s.l. on April 30, 1976. The study area is situated within the rectangle.

For calculation of the cumulative runoff, a starting point had to be chosen. The date when the runoff rises above the winter level, due to the start of snow melt, was chosen for this purpose. The runoff data for 1976 were, however, not available before the termination of this study.

The dates for increase in runoff due to the start of snow-melt in the four basins was as follows:

BREIM : April 21, 1975  
JOSTEDAL: April 24, 1975  
BOEVRA : May 6, 1975  
OLDEN : May 7, 1975

The cumulative runoff of the various basins was then calculated in  $10^6 \text{ m}^3$  from the dates mentioned above. Measurements in the Jostedal basin show that for the years 1950-1975 the average annual runoff is  $871 \cdot 10^6 \text{ m}^3$  and that 90 per cent of this annual runoff occurs normally between May and September. The total runoff in 1975 between April 24 and August 1 was  $910 \cdot 10^6 \text{ m}^3$ , and this indicates that the runoff was well above average (compare Fig. 19). The same situation was also found in the three other basins.

Though the complete sets of runoff data for 1976 are not yet available, it is clear that the runoff in 1976 was also well above average. This can be explained by the great amount of snow in the mountains and the considerably warmer and sunnier weather than normal during the summer of 1975 and 1976.

#### SNOW ON LANDSAT IMAGES

This study has shown that LANDSAT imagery is very suitable for snow-mapping. MSS 4 and 5 proved to be highly redundant, but the latter is best due to better contrast and greater penetration through haze and fog. During winter and early spring, we observe high redundancy between MSS 4 and 5 on one hand, and between MSS 6 and 7 on the other. On LANDSAT images taken during the summer, the extent of snow in the MSS 5 band is much greater than in MSS 7.

## THE SNOW LINE

In this study the snow line plays a dominant role since it defines the border between snow-covered and snow-free areas. To find the size of a snow-covered area, the position of the snow line must be determined. Usually the snowline is not strictly a well-defined and simple line, but rather a transition zone between a completely snow-covered area and bare ground. There are several factors that influence the nature of the snow line, such as season and topography. In mountains during the fall it was possible to observe a well defined snow line after the earliest snowfalls of the season. Clearcut snow lines along mountain slopes can also be observed on some LANDSAT images of Norway obtained during the fall.

## TECHNIQUES

The LANDSAT images used in this study were examined with a Zeiss Interpretoscope which proved to be a very suitable instrument for studying this type of satellite imagery. Optical pantographs were used to draw basin boundaries, i.e. to transfeere them to the working scale of 1:250000. In some special cases this instrument was also used to draw the snow line from 1:1 mill LANDSAT positive transparencies. However, in this study, snow mapping is based on the use of photographic black and white paper copies at the scale of 1:250000, (compare Figs. 12 and 13).

Two copies were enlarged for each date and each basin. These paper prints were made somewhat darker than normal in order to obtain the snow-cover as white as possible in contrast to the snow-free areas. By comparison with MSS 5 1:1 mill transparencies, the paper copy which was in the best agreement with it, was selected.

On the selected prints, the basin boundary was drawn and, by means of planimetry, the snow-covered areas were measured. Due to the special nature of the snow line, dot-planimetry was employed. The accuracy of the dot-method was tested. One area of known size was measured three times, and the same was done with the snow-cover in one of the basins.



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Fig. 12

An example on how the snow-cover decreases in size within the study area during the summer melting. The Jostedal basin shown on an MSS 5 enlargement of LANDSAT image from July 5, 1976.

Scale 1 : 360000

Image No.: 2530-10073



Fig. 13

As for Fig. 12, but presenting the situation 63 days later.

An Additive Color Viewer has been used to make multispectral color images of the study area. These images do not seem to give any substantial new information of the snow-cover, compared with black and white MSS 5 images. However, color images are very valuable in providing additional information such as the position of the transient snow line on glaciers and suspended sediment loads in lakes and rivers.

#### ACCOMPLISHMENTS

Inherent in the LANDSAT-system is the ability to observe large areas simultaneously. This is a great advantage because the snow-cover can be monitored over extensive areas. Most of the weather stations are in the lowlands and the valleys, while there are only few stations located in the almost inaccessible high mountain areas.

Thus, the in situ information of the snow-cover in the high mountains is difficult to obtain. The LANDSAT images provide valuable additional information on snow conditions and show melting in the Norwegian mountains. Ground truth, particularly meteorological information like snow depth, is available from a number of stations. Snow depth information from the Boevra basin in 1975 have been tested and the snow distribution on LANDSAT images agree well with these data.

By combining LANDSAT images from 1975 and 1976, it has been possible to map the reduction of the snow-cover successfully from the middle of May to the end of August. In this period most of the snow melting takes place in mountainous Norway (compare Figs. 14, 15, 16 and 17).

#### SIGNIFICANT RESULTS

During the summer seasons of 1975 and 1976 the snow-cover has been successfully monitored and measured in the four basins studied. By the use of the elevation distributions for these basins combined with the measured snow-cover percentages, the equivalent snow line

altitude was calculated. Equivalent snow line altitude is used in accordance with Mark Meier's definition. The results are seen in the Tables on page 19.

Cumulative runoff data have been collected for the basins. Tables showing percentage snow-cover versus cumulative runoff have been worked out for 1975. Runoff data for 1976 are not yet available. Because of the lack of complete data on runoff, the analysis of the results have to wait until all data become available. This has to be done as a post project work (see Figs. 18, 19, 20 and 21).

#### PROBLEMS

Only a limited number of images of all possible LANDSAT passes in 1975 and 1976 were acquired and therefore the image frequency was not as high as it could have been with maximum utilization.

Clouds have been a minor problem in this study because most of the images used were cloudfree. However, in some cases, small clouds were identified and corrected for. Nor do shadows represent a great problem. The Norwegian mountains are generally rather smooth, forming an undulating landscape. A landscape like this is present in the study area, but rougher terrain is also present, particularly in the western parts where the fiords dissect deeply into the mountain massif. During the period from which LANDSAT data have been used in this study, the sun angle has been between 35 and 50 degrees. This, and the fact that the snow was mainly confined to higher elevations on the plateau, is the reason why shadows were not a real problem.

Misinterpretation caused by high reflective barren terrain is also a minor problem. In the highest parts of the Norwegian mountains, there are quite extensive block fields where there is very little or no vegetation. These block fields have in certain areas very high reflection which could be interpreted as snow by inexperienced observers. Due to the heavy snowpack in the study area, the majority of these block fields were snow-covered during most of the summer in 1975 and in 1976.

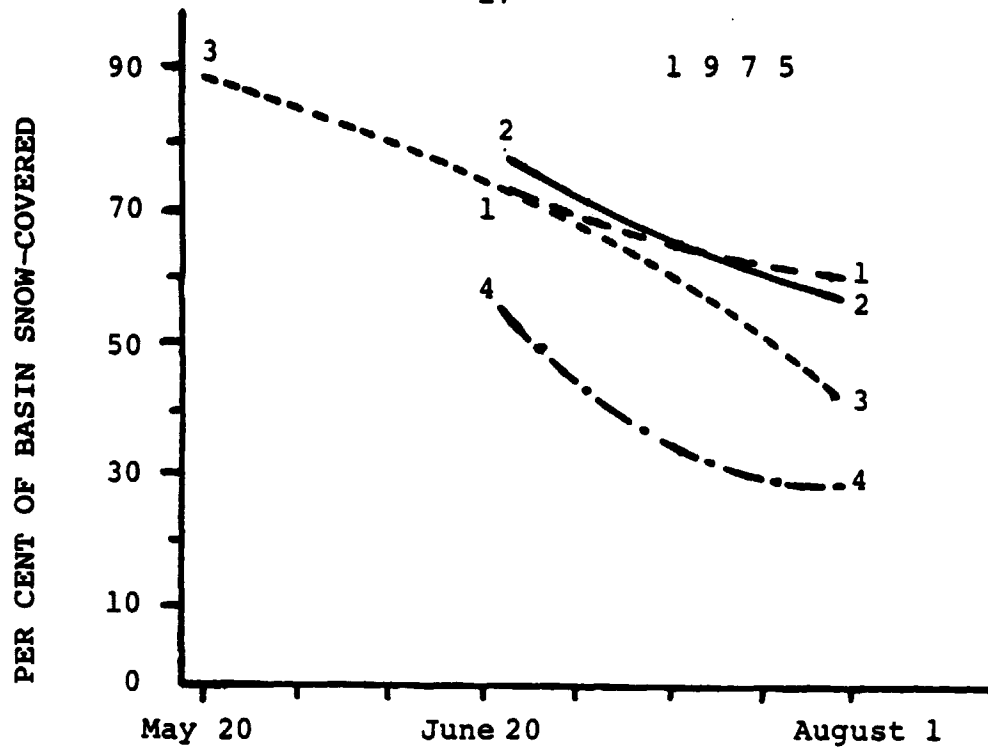


Fig. 14

Snow extent variation in four Norwegian basins:

- 1: Olden
- 2: Jostedal
- 3: Boevra
- 4: Breim

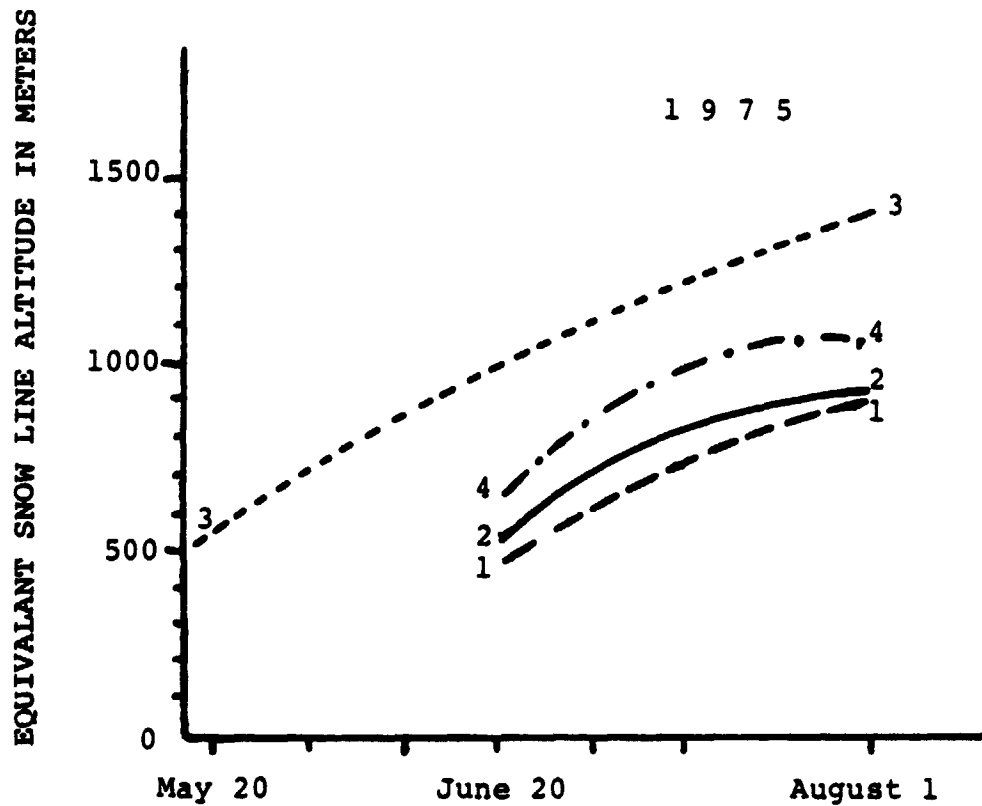


Fig. 15

Time variation of equivalent snow line altitude in the four basins:

- 1: Olden
- 2: Jostedal
- 3: Boevra
- 4: Breim

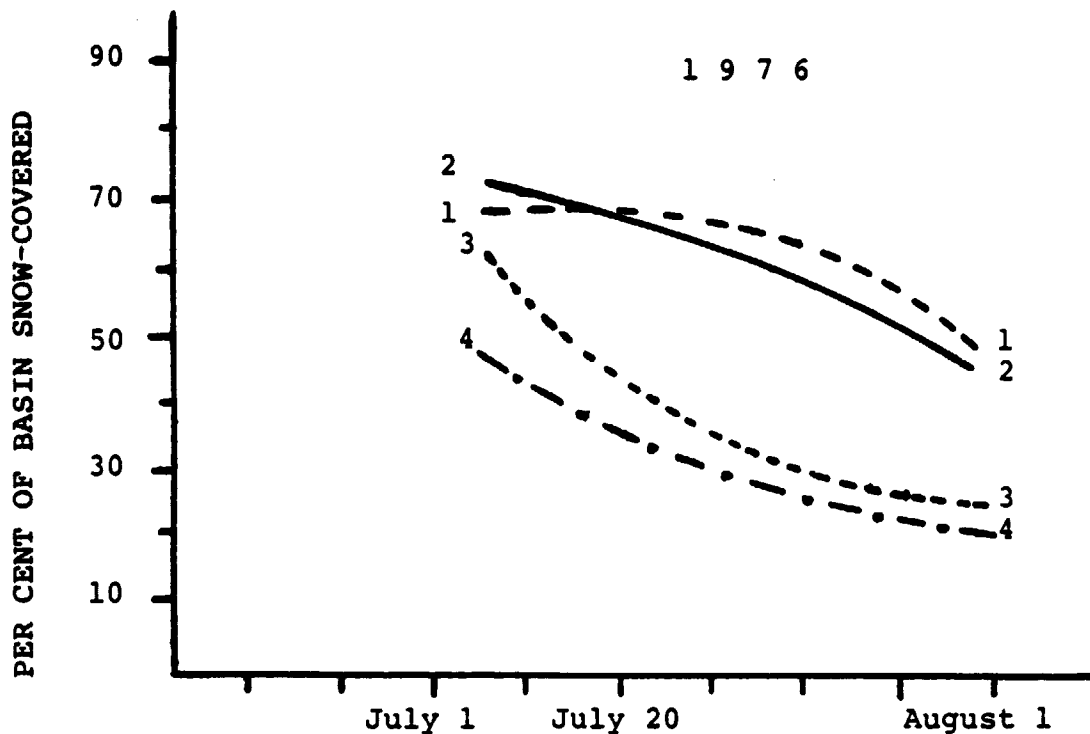


Fig. 16

Snow extent variation in four Norwegian basins:

- 1: Olden
- 2: Jostedal
- 3: Boevra
- 4: Breim

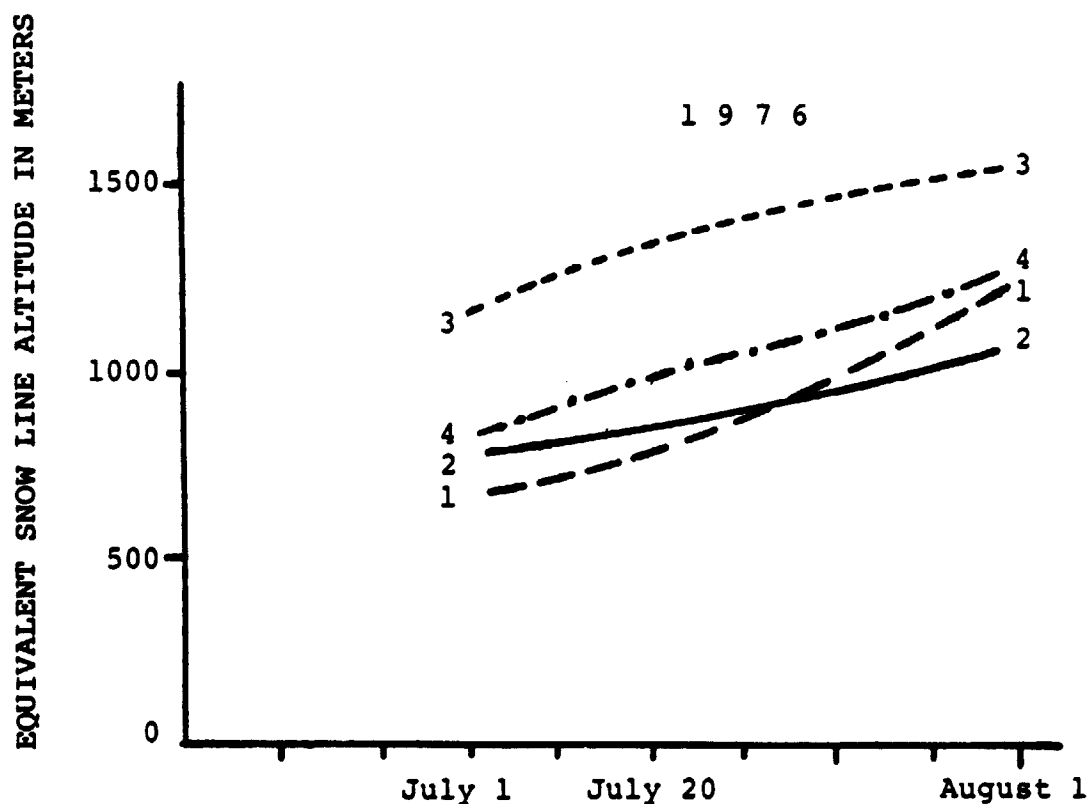


Fig. 17

Time variation of equivalent snow line altitude in the four basins:

- 1: Olden
- 2: Jostedal
- 3: Boevra
- 4: Breim

DATE	BOEVRA	JOSTEDAL	OLDEN	BREIM
May 16, 1975	90%			
June 22, 1975	72%	78%	74%	54%
July 5, 1976	59%	69%	68%	46%
July 10, 1975	59%	68%	67%	32%
July 28, 1975	44%	58%	61%	29%
August 9, 1976	29%	56%	60%	27%
August 27, 1976	26%	44%	46%	21%
Percentage of the basins covered with glaciers	11	27	36	12

Table 1:

Percentage of snow-cover in the four basins.

DATE	BOEVRA	JOSTEDAL	OLDEN	BREIM
May 16, 1975	530 m			
June 22, 1975	1000 m	520 m	480 m	700 m
July 5, 1976	1210 m	800 m	670 m	820 m
July 10, 1975	1210 m	820 m	740 m	1000 m
July 28, 1975	1350 m	910 m	900 m	1050 m
August 9, 1976	1440 m	940 m	970 m	1100 m
August 27, 1975	1480 m	1030 m	1220 m	1240 m

Table 2:

The equivalent snow line altitude in meters above sea level, obtained by combining data on the percentage of snow-cover and elevation distribution of the four basins.

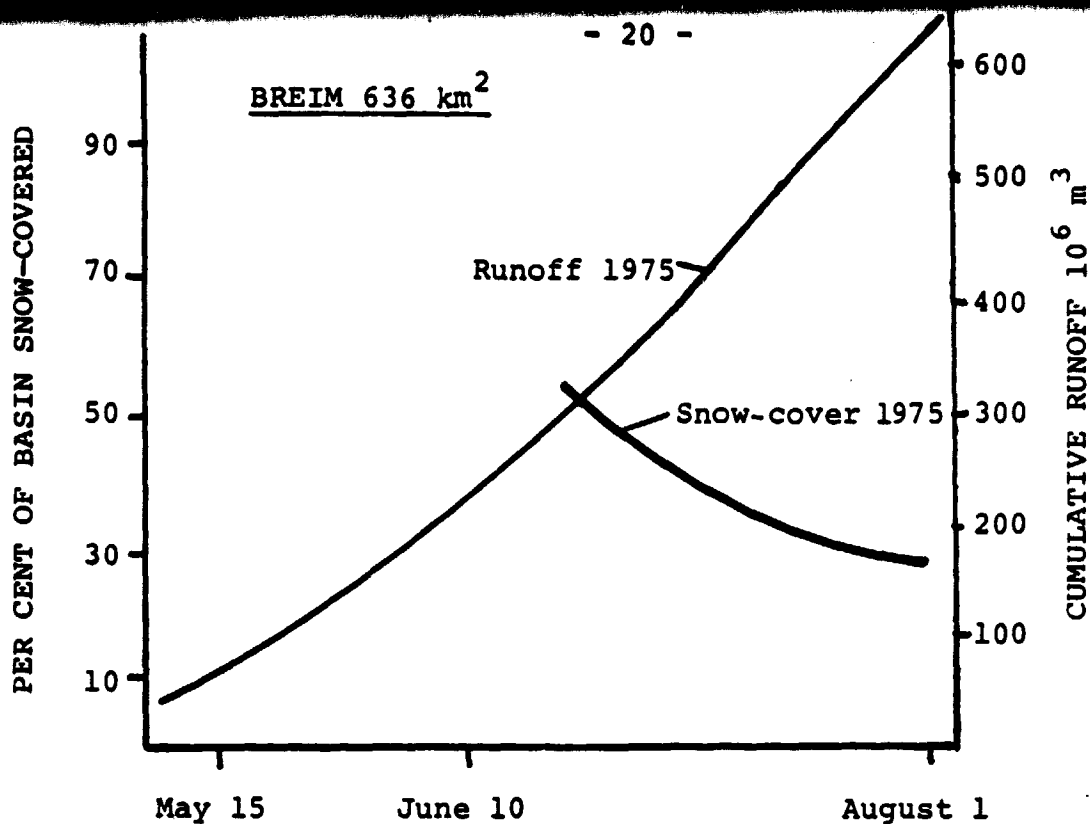


Fig. 18

Variation in snow-cover versus cumulative runoff.

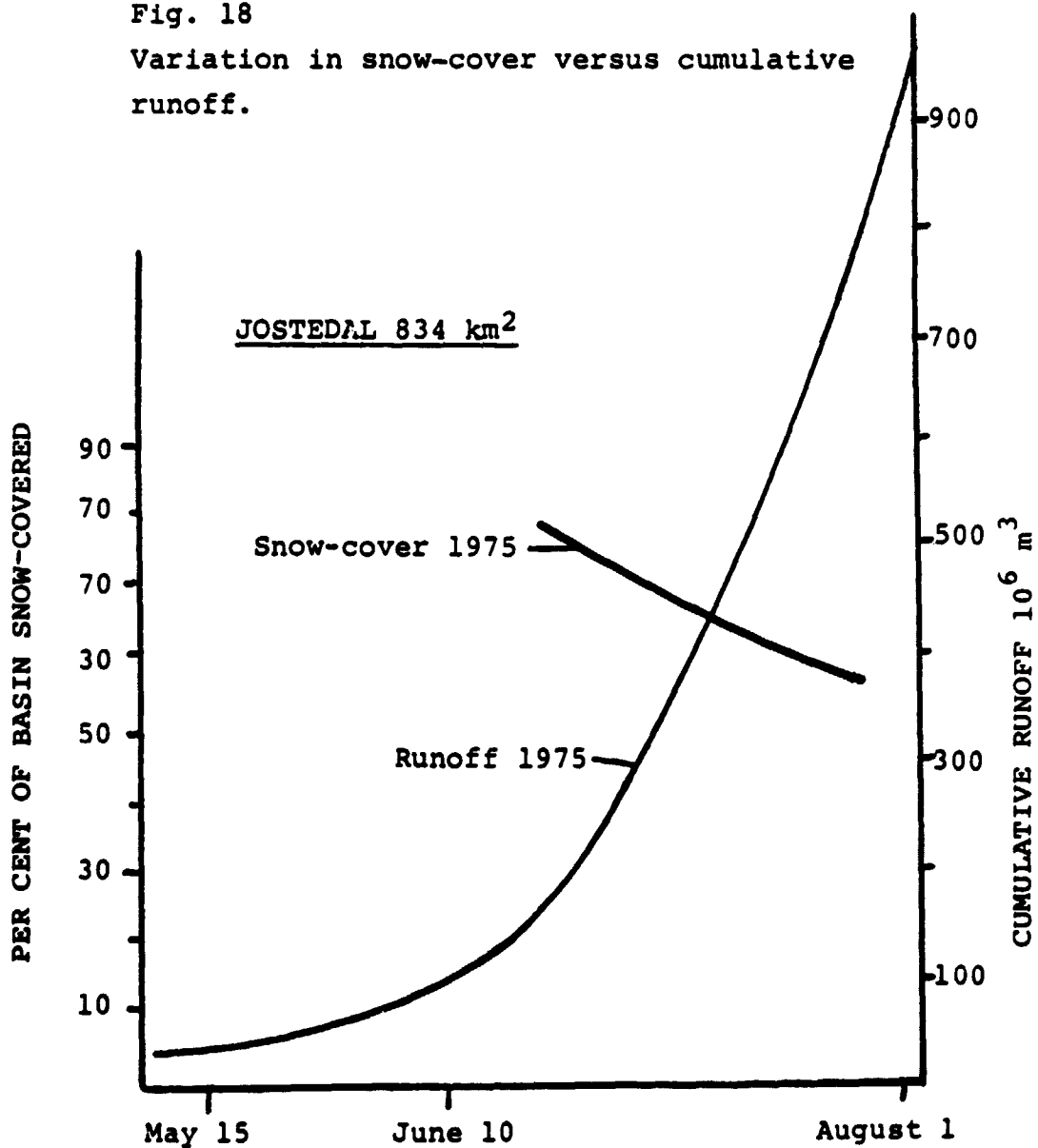


Fig. 19

Variation in snow-cover versus cumulative runoff.



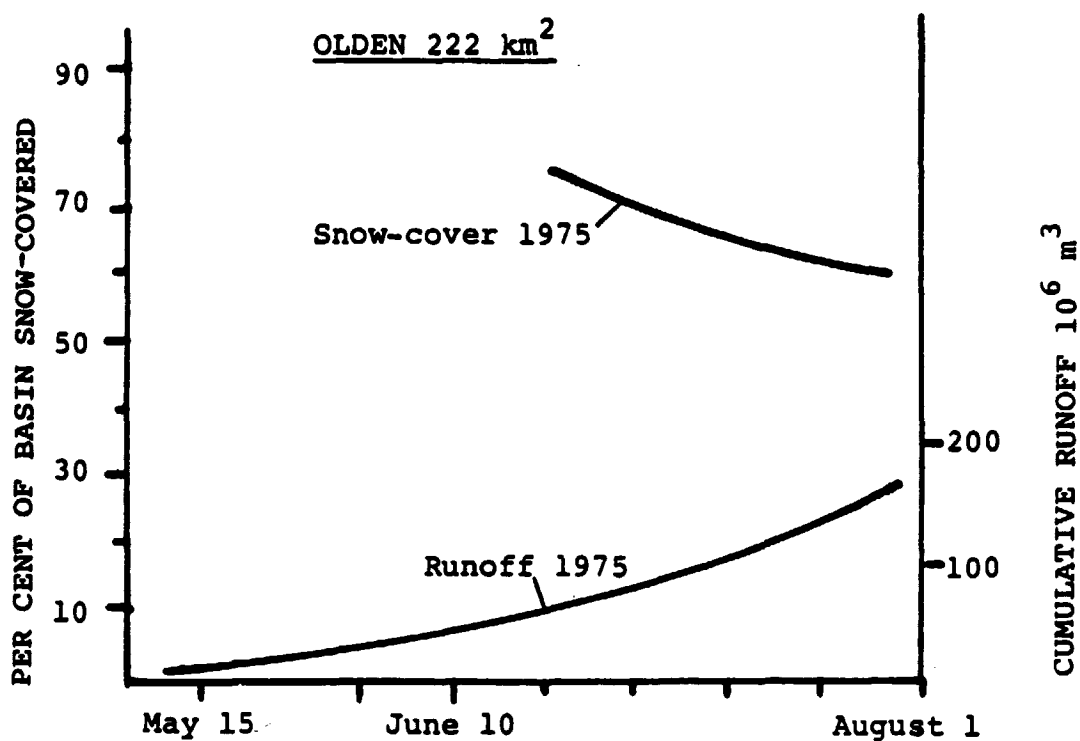


Fig. 20

Variation in snow-cover versus cumulative runoff.

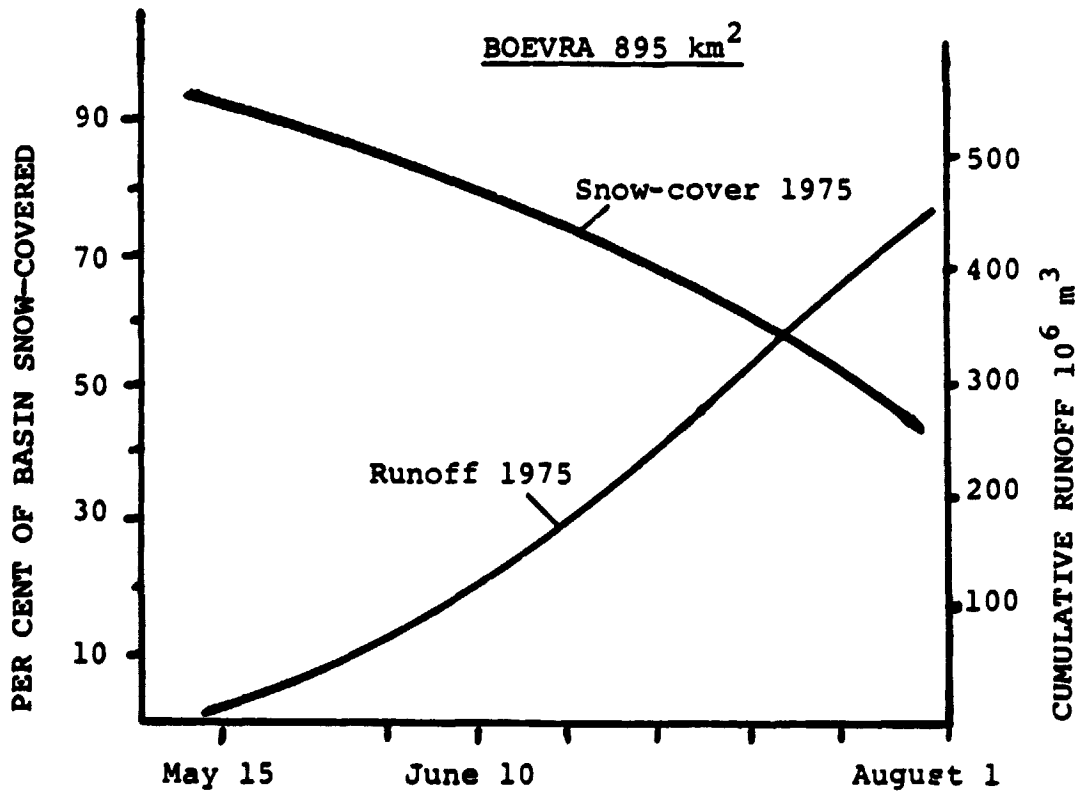
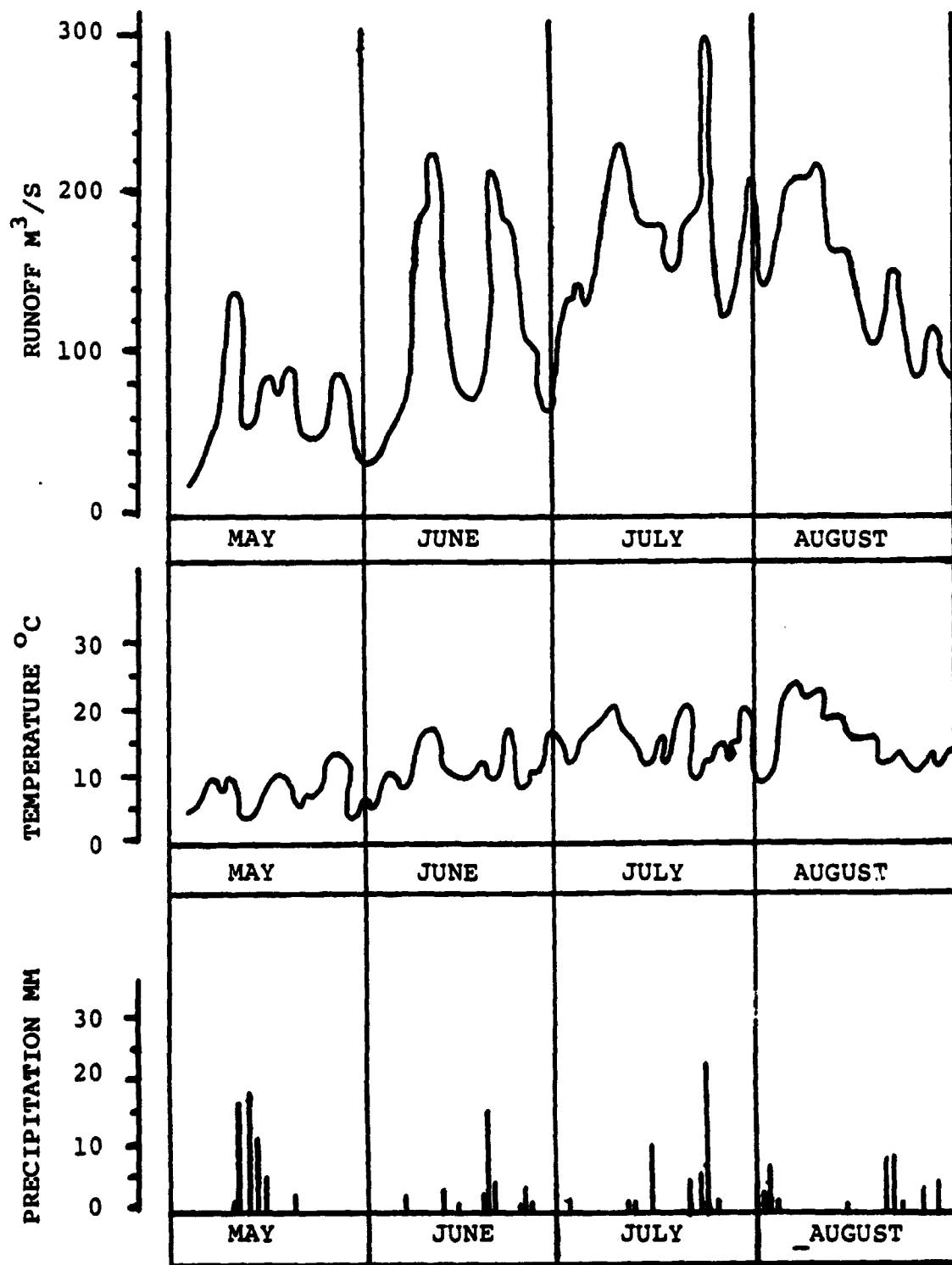


Fig. 21

Variation in snow-cover versus cumulative runoff.



(S. Harsten 1976)

Fig. 22

Runoff, air temperature and precipitation at the base of the Jostedal river in 1975.

In this study as well as for all use of LANDSAT imagery the general lack of adequate interpretation instruments in Norway is a problem.

#### DATA QUALITY AND DELIVERY

The quality of LANDSAT images used in this study has been very good and the delivery of data has been as expected. In some cases it is considerably easier to distinguish between snow and ice on positive MSS 7 transparencies than on negative MSS 7. This makes it difficult to produce good positive paper prints if one wants to distinguish between snow and ice.

#### RECOMMENDATIONS

Satellite observation of snow-cover is a valuable tool for water management. However, the same can be said of the more general management of the mountain areas since phenological conditions are clearly seen on LANDSAT imagery. Satellite monitoring of mountain areas is therefore desirable and valuable both for practical and more scientific applications.

This study is based upon images from only a smaller part of all possible LANDSAT passes over the study area during the melting season. A recommendation for future use of LANDSAT in snow monitoring, is to exploit fully the use of a Nordic LANDSAT station.

For operative use of LANDSAT data for snow mapping, it is important to have images available a few days after they have been acquired. The present spacing between LANDSAT passes together with an east-west overlap varying between 56 and 71 per cent, should provide a useful though not satisfactory basis for supplying data for operational snow monitoring satellite system.

Snow is easily identifiable on LANDSAT images and digital processing is not necessary, but it would obviously improve the accuracy.

In the first phase of photointerpretation quite simple procedures should be adequate, like enlarging MSS 5 to a suitable, standard scale and with a set of pre-cut basin masks the planimetry work could be performed rapidly.

A set of pre-cut basin masks would also be very useful if an electronic densitometer/planimeter is available.

One should also take advantage of the progress within the LANDSAT and other satellite systems. The thermal scanner on LANDSAT C should, in spite of the lower resolution than the present MSS scanner, give valuable information on the processes of breakdown of snow-cover since it might be possible to find and plot the  $0^{\circ}\text{C}$  isotherm at the boundary of snow-melt. In addition, day and night measurements should give information on the thermal inertia in areas with snow and bare ground.

The use of the RBV cameras of LANDSAT C with high resolution imagery, should make it possible to improve the interpretation. It is desirable to clarify to what degree data from the Heat Capacity Mapping Mission satellite can improve the monitoring of snow.

NOAA satellites do provide a frequent coverage and the VHRR images have a useful resolution. A combination of LANDSAT and NOAA data could be a good solution for the near future. However, new satellites with sensors which are less affected by weather would surely make monitoring of snow more effective.

## CONCLUSION

This study shows that the LANDSAT images are well suited for snow-mapping in Norwegian mountain areas. It is clear that changes in snow cover are slower in the western mountain regions of Norway than in the eastern areas. This makes the western parts of Norway less sensitive to the rather infrequent LANDSAT observations.

The 1975 and 1976 situations are not representative of the normal snowpack conditions, and therefore additional satellite observations are desirable. Data on variations in snow-cover and runoff accumulated over several years will prove to be a valuable tool in water management. Since a small improvement here can result in large savings, the satellite observation of snow should continue and be improved.

#### ACKNOWLEDGEMENTS

The author is grateful to the Principal Investigator, Helge Ødegaard, for his support during the study and for making available the LANDSAT films from the 1975 season. NASA's Technical Monitor, Mr Frederick Gordon of GSFC, kindly contributed with valuable advice. During a visit to the USGS Tacoma Office, Dr Mark Meier and his colleagues gave the author a most inspiring and rewarding introduction to their application of LANDSAT imagery to snow hydrology. The author also feels indebted to the instructors at the ERTS Image Interpretation Training Course, EROS Data Center, Sioux Falls, for showing the many possibilities inherent in the LANDSAT system. The author also wishes to thank the Royal Norwegian Council for Scientific and Industrial Research (NTNF), Space Activity Division for their assistance in preparing this report.

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